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### W and Z boson production in 5.02 TeV *pp* and *p*+Pb collisions with ATLAS



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### W and Z physics at LHC



24 September 2016, Wuhan

#### W and Z production at 5.02 TeV

### W and Z physics at LHC



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### ATLAS detector at LHC



## Zboson in p+Pb @ 5.02 TeV



- Z boson yields asymmetric in y
- shape better described with models containing nuclear PDF modification

## Zboson in p+Pb @ 5.02 TeV

Phys.Rev. C92 (2015) 35 ATLAS enhancement p+Pb 2013, L \_ = 29 nb<sup>-1</sup> 30  $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ dσ(Z→ II)/dy<sub>z</sub>\* [nb] 25 20 15 CT10 (NLO) 10 CT10+EPS09 (NLO) STW2008 (NNLO) 5 1.5 1.0 Data / CT10 (NLO) 0.5 Data/Model 0.2 0.2 .5 Data / CT10+EPS09 (NLO) 1.5 1.0 Data / MSTW2008 (NNLO) 0.5 -2 0 2

- Z boson yields asymmetric in y
- shape better described with models containing nuclear PDF modification
- models with CT10 PDF set underestimate total cross section

$y_Z^*$	[-2, 0]	[0,2]	[-3, 2]	[-3.5, 3.5]
$Z \rightarrow \mu \mu$	$54.2 \pm 1.6 \pm 1.3$	$45.3 \pm 2.1 \pm 0.9$	$118.2 \pm 3.3 \pm 2.6$	N/A
$Z \rightarrow ee$	$55.1 \pm 1.8 \pm 5.9$	$46.5 \pm 2.2 \pm 5.0$	$121 \pm 3 \pm 13$	$143 \pm 5 \pm 17$
$Z \to \ell \ell$	$54.4 \pm 1.3 \pm 1.4$	$45.9\pm1.4\pm1.4$	$119.3 \pm 2.2 \pm 3.4$	$139.8 \pm 4.8 \pm 6.2$
CT10 (NLO)	$47.4 \pm 0.9$	$46.8\pm0.9$	$110.8 \pm 2.9$	$132.2 \pm 3.3$
CT10+EPS09 (NLO)	$48.7 \pm 1.0$	$43.5 \pm 1.1$	$108.6 \pm 3.1$	$127.4 \pm 3.6$
MSTW2008 (NNLO)	$48.3^{+1.2}_{-0.9}$	$47.9^{+1.2}_{-0.9}$	$113.5^{+2.8}_{-2.2}$	$135.2^{+3.4}_{-2.7}$

... or overal normalisation shift and deficit?

### Wboson in p+Pb @ 5.02 TeV

ATLAS-CONF-2015-056



- isospin effect: W<sup>+</sup> bosons having on average a higher fraction of the proton momentum
- W<sup>-</sup> boson measurement points are higher than the model prediction
- lepton charge asymmetry: data are somewhat lower than the calculation on the Pb-going side
- consistent with Z results

$$A_{\mu} = \frac{dN_{W}^{+}/d\eta - dN_{W}^{-}/d\eta}{dN_{W}^{+}/d\eta + dN_{W}^{-}/d\eta}$$
charge asymmetry

## Centrality and nPDF effects

ATLAS-CONF-2015-056



• W boson pseudo-rapidity differential yields in centrality classes indicate centrality dependence of the modification

# Centrality and nPDF effects



- rapidity differential yields in different centrality classes show common trend:
   *asymmetry* and *enhancement*
- ratio of central to most peripheral yields seems to exhibit linear behaviour
- Z boson measurements suggest centrality dependance of PDF modification

# pp reference data @ 5.02 TeV

3/13 3/

# ATLAS

Run: 267638 Event: 242090708 2015-06-14 01:01:14 CEST

# Zboson in pp@5.02 TeV

Event selection

- 2 high quality reconstructed muons with  $p_T > 20$  GeV and inside  $|\eta| < 2.4$
- requiring low level of multi-jet background (*isolation*)
- opposite charge pairs with invariant mass between 66 and 116 GeV
- 7293 Z boson candidates
- total (24.7 ± 1.3) pb<sup>-1</sup> of data

#### Signal and background



# Zboson in pp@5.02 TeV

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#### Signal and background



# Zboson in pp@5.02 TeV

#### Corrections

#### Systematics

- fiducial space:  $|y^{Z}| < 2.5$ , 66 GeV < m<sub>Z</sub> < 116 GeV
- data unfolded with corrections from simulation
- corrections differential in rapidity

Source	Uncertainty range [%]	
Muon Identification & Reconstruction	1-1.5	
Muon Trigger	1-1.2	
Muon Isolation	0.05-1.6	
Background	<0.1	
Unfolding	0.2-4	
Luminosity	5.4	

### Integrated cross section @ 5.02 TeV



- $\sigma_{Z(\text{fiducial})} = 590 \pm 9(\text{stat}) \pm 11(\text{sys}) \pm 32(\text{lumi}) \text{ pb}$
- NNLO calculations including CT14 PDF set: 573 <sup>+13.94</sup><sub>-15.96</sub> pb
- models with CT10 PDF sets underestimate the integrated cross section by ~9%

### Differential cross section @ 5.02 TeV



- rapidity differential cross section in agreement with CT14 @ NNLO
- *pp* reference for *Z* boson
   *p*+Pb results

# Is there nuclear modification in p+A system seen by the EW probe?

## Nuclear modification factor

ATLAS-CONF-2016-107

$$R_{pPb} = \frac{d\sigma^{pPb}/dy}{A_{Pb} d\sigma^{pp}/dy}$$

- relative suppression in forward rapidity (low Bjorken x of Pb)
- consistent with nuclear PDF modification



## Nuclear modification factor

ATLAS-CONF-2016-107



 isospin effects on the Pb going side (negative rapidity) but not describing deficit in positive rapidity



What seemed to be enhancement was rather scale offset and deficit...

## R<sub>pPb</sub> in centrality classes



## R<sub>pPb</sub> in centrality classes



## R<sub>pPb</sub> in centrality classes



## Summary

- measurements of Z and W boson production provide benchmark for understanding centrality and PDF modification in collisions with heavy nuclei
- Z boson fiducial cross section measured in pp system at 5.02 TeV
- models with new CT14 PDF set better describe Z boson yields
- new pp reference data improves our understanding of centrality dependant nPDF
- measured  $R_{pA}$  indicates presence of nuclear modification that increases with centrality of the p+A collision

# Anticipating Pb+Pb results



...new Pb+Pb measurements coming soon!

### Backup

### Zboson decay in ATLAS @ 5.02 TeV



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# Geometry and centrality



- FCal energy as a measure of collision activity → data is divided into centrality classes
- geometrical quantities from simulation
- Z boson production rate expected to scale with the overlap of the two colliding nuclei ( $\langle T_{AB} \rangle$ )

# Centrality in p+Pb system



- challenging due to asymmetry and less activity compared to Pb+Pb system
- centrality bias correction applied for the correlation of hard process and underlying event used for determining collision centrality
- several geometrical models: Glauber and Glauber-Gribov color fluctuation model

### EW boson scaling in p+Pb system



- uncorrected Z and W boson yields grow with centrality
- Gribov color fluctuations or centrality bias correction lead to well understood picture of binary scaling

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